Tacoma, Washington.

Arctic seal.

Predicting Environmental Change

As the debate intensifies over possible man-made influence on climate, scientists are working to discover and understand links between the atmosphere and the ocean, and natural climate variability across the globe. Global climate change is a recurring theme throughout Earth's history. The presence of continental ice sheets and concurrent drops in sea level have left spectacular evidence of past climate cycling. Follow NURP researchers on a journey to lost continents beneath the ocean to learn about how past climate history holds clues about potential climate change in our future.

An important part of our atmosphere, carbon dioxide, contributes significantly as a greenhouse gas that can effect global climate change. To narrow the uncertainties about the global effects of carbon dioxide, and to improve our understanding of the trends and forcing of greenhouse gases, NURP researchers have focused on the ocean's exchange of carbon dioxide with the atmosphere, and the ocean's vast reservoir of carbon. Until it is fully understood how carbon is regulated by biological, chemical, and physical processes in the ocean, the many roles of atmospheric carbon dioxide cannot be accurately understood.

In this chapter, we learn how a NURP researcher succeeded in measuring the cycling of carbon dioxide in the coastal ocean. We also learn how submerged islands, coral reefs, and underwater volcanos found in the oceans of North America offer important clues about climate history and possible triggers that cause climate change.

Recorders of Climate History

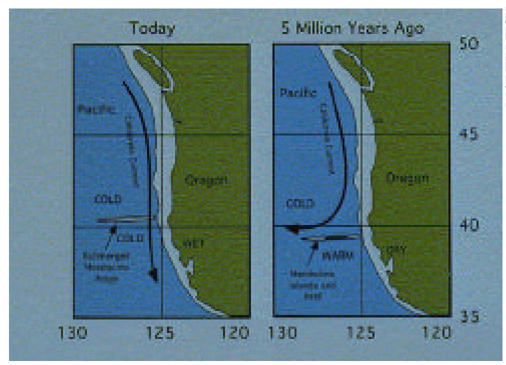
As our knowledge builds regarding man-made influences on climate, scientists are working to discover and understand links between the atmosphere and the ocean, and natural climate variability across the globe. Submerged islands, coral reefs, shorelines, and underwater volcanos found in the oceans offer important clues about climate history and possible triggers that cause climate change. Understanding the link between the atmosphere and ocean is a key goal of climate research funded by NURP. Just as the growth rings of a tree tell its age, scientific evidence for climate change is contained in the physical and chemical properties of the sea floor.

Long-term changes in climate, those that occurred millions of years ago, can come from slow changes in the configuration of the ocean basins and continents. Continental drift, also known as plate tectonics, has moved India and Southern Africa from regions where they were ice covered to their present tropical and temperate conditions. Ocean currents such as the Gulf Stream also control the climate and are controlled by the motion of the Earth's surface. Plate tectonics can block and divert these currents. A recent NURP-funded study found that an undersea ridge off northern California rose well above sea level some five to seven million years ago. This ridge blocked the cold, southward flowing California current and changed the climate in the Pacific northwest. This finding is important because it will help scientists understand how the currents in the Pacific historically affected the climate of North America.

Mendocino Ridge, a major submerged mountain range along one of the Earth's largest fracture zones some 1,200 m (4,000 ft) below sea level, was once a string of islands off the coast of San Francisco. The ridge was uplifted through the collision of the Pacific and Gorda plates some five millions years ago, then subsided through sheer weight. Thirty-seven years ago, oceanographer Dale Krause at the Scripps Institution of Oceanography theorized that the ridge had been at sea level, but it wasn't until 1995 that he got proof. Diving in U.S. Navy submersibles *Sea Cliff* and *Turtle* and using a remotely operated vehicle, two Oregon State University geologists Martin Fisk and Robert Duncan observed smooth boulders at the crest of the Mendocino Ridge similar to those found on rocky beaches today.

The California current that comes out of the Gulf of Alaska delivering cold water down the coast of California would have been blocked by the newly discovered island chain, and warm water from the south would have drifted north along the coast. "This could have set up circulation systems that would have changed climate," Fisk said.

Did the submerged island chain trigger the advent of the ice age that started two million years ago? "Something triggers these long episodes of ice," Fisk said. "If we can figure out what happened to the climate of California and Oregon when the current was blocked, we should be able to better understand what effects our climate today." Better models of how the Earth's plates moved and their effect on climate in the past will help scientists estimate the effects of other recent changes like global warming, he said.



MARTIN FISK

Maps of the California Current today and in the past. The emergence of the Mendocino Islands five million years ago could have diverted the California Current to the west. This would have allowed warm water to drift north to where San Francisco is today. Northern California is probably wetter now than it was then.

Coral reefs are also exceptional recorders of climate history. Despite their fragile beauty they have managed to survive for the last 500 million years of Earth's history, and kept a diary of changes along the way. NURP-funded scientists are unfolding the secrets kept by ancient coral reefs and lost shorelines that laid the foundation for the distribution of reefs in South Florida today. They are studying the reefs to learn about past sea level and climate, as well as to learn what makes corals grow or die.

About 125,000 years ago at sites now occupied by Miami and Key West, huge sand bars were created by strong tidal currents.

Hurricane damage.

The two cities now lie at either end of an ancient coral reef established on top of the sand bar which we now know as the Florida Keys. Where bait and tackle shops, motels, and dive shops dot the scenic road through the Keys, a vast living reef once flourished. “Sea level was 20 feet higher than it is now,” said Eugene Shinn, project chief of the U.S. Geological Survey (USGS) in St. Petersburg, Fla., “and a coral-studded shelf extended east five miles to the edge of the Gulf Stream.” Shinn has studied coral rocks for the past 35 years to gain information about what the environment was like in the past, as a way to predict how it might respond in the future. His work on coral reefs is extensive. Underwater excavations, rock corings, and acoustic surveys of rock outcroppings and sediments, have enabled the geologist to build a picture of how reefs were distributed in Florida during the ice age known as the Pleistocene Epoch. The carbon-14 method allows him to date peat from underwater, in swamps, beneath reefs, and under reef sands. Since peat only forms above sea level, scientists can use it as a marker of sea level history in the last 10,000 years. Growth bands in the skeleton of corals also preserve a record of seawater temperature and salinity during this period.

Why reefs exist in some regions of South Florida today and not in others is still a subject of ongoing research. After the last ice age flooding, reefs began to grow on topographic highs in some areas of the region, but not in others. In a process called backstepping, geologists observed how reefs grew upward and landward away from the sea in response to rising sea level. Those that couldn’t keep up with sea level rise died, Shinn said.

“Corals, which have survived for the last 500 million years of Earth’s history, will certainly live through the vagaries of sea level oscillations well into the future,” Shinn said. Increasing population and coastal development, however, may pose a greater, added threat to these ancient ecosystems. Marine sanctuaries that afford reefs protection will enhance their survival, he said.

Undoubtedly, alternating periods of freezing and thawing had a significant effect on the ocean and the continents themselves. Sediment cores taken off Wrightsville Beach, a barrier island in the southeastern part of North Carolina, helped NURP researchers reconstruct a picture of how climate shaped the landscape since the height of the last glacial period. Geologists Orrin Pilkey and Robert Thieler of Duke University found the remnants of a 9,000-year-old barrier island lagoon system located 8 km (4.9 mi) offshore. At the peak of the glacial period, coastal plains near the edge of the continental shelf were fronted by lines of sand dunes. Rising sea level caused the ocean to break through the dunes and form a lagoon, a long, shallow body of seawater isolated from the ocean. The high lines of coastal dunes became islands. As sea level continued to rise, wave action caused the islands and lagoons to migrate landward running over old rivers and estuarine deposits from previous lower sea levels.

Over the last several thousand years many barrier islands have grown by accumulating sediment from the continental shelf. Today, Wrightsville Beach and many other islands are eroding along both their lagoon and ocean shorelines containing the natural pieces documented by those researchers who suspect this may be a result of an increased rate of sea level rise.

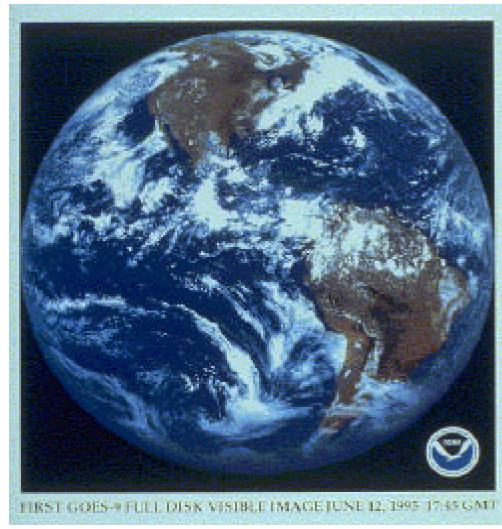
In the future, if the ocean were to expand and the polar ice caps were to melt, sea level could rise driving the coast inland even further. The impacts to coastal cities (where one-third of the world's people live), deltas, and wetlands would be astronomical.

"The big question now," said Thieler, "is when and how fast future climate change will be."

Oceans' Role in Climate Change

Natural greenhouse gases—from volcanic processes to the decay and burning of organic matter to biological respiration—keep the Earth warm. What prevents the planet from overheating is the removal of these gases by plant photosynthesis and seawater absorption. But now it appears carbon dioxide primarily from combustion of fossil fuels may be produced at a rate faster than it can be assimilated by biotic respiration or the ocean. To make matters worse, forests and jungles are clear-cut and their absorption lost. Global temperature is on the increase since the last ice age. However, scientists are still uncertain about the magnitude of human-induced component of global warming. Unpredictable natural processes like the fluctuation of energy output from the sun or the eruption of volcanos like Mt. Pinatubo in the Philippines that release dust and gas (for example, carbon dioxide) into the atmosphere can greatly influence temperature. The submarine volcano, Loihi, also introduces natural gases and particles into the undersea environment. Loihi, which is

NOAA



First GOES-9 image of clouds over the Americas.

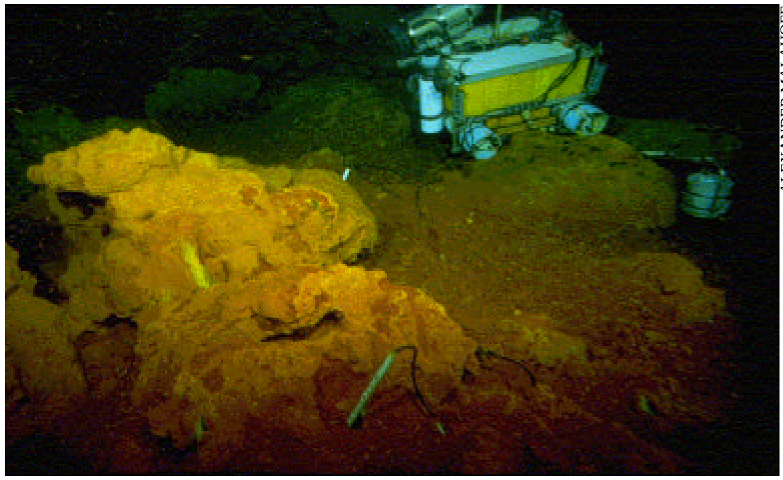
only one of the hundreds of thousands of submarine volcanoes, is part of an emerging link of islands along the Pacific Plate and has been under intense study since two years ago when the largest set of earthquakes ever recorded shook the seamount.

A series of dives in the submersible vehicle *Pisces V* led by NURP scientist Alexander Malahoff, director of NURP's Hawaii and Western Pacific Undersea Research laboratory, enabled scientists to observe an island being formed and the chemical processes that occur during such an event.

Using Loihi as a natural laboratory for continued studies will be important in understanding the role that hydrothermal vents play in the global carbon system. Along with atmospheric influences, carbon cycling in the deep ocean is necessary for modeling and predicting global chemical and climactic change in the future, said microbiologist James Cowen of the University of Hawaii. What is the total export of carbon from hot spots into the atmosphere? Do these submarine volcanos have a major impact on global warming? If most of the carbon dioxide released from the Earth's mantle did not get bound up in sediments and unrespired organic carbon, the Earth's atmosphere would be similar to that of Venus, where carbon dioxide constitutes 95 percent of the atmosphere. Clearly, the ocean is a major reservoir of carbon, but how is it responding relative to increases in carbon dioxide from human activities in the last 200 years? This is one of the most important questions of chemical oceanography today, NURP researchers said.

Until it is fully understood how carbon is regulated by biological, chemical, and physical processes in the ocean, atmospheric carbon dioxide cannot be accurately modeled. Present evidence suggests that the ocean is a major sink for carbon dioxide from anthropogenic sources.

Modeling the distribution of carbon dioxide in the coastal ocean is more difficult than the deep sea because of its variability including huge seasonal shifts in the biotic productivity, as well as an immediate chemical exchange of carbon between the sea floor and the surface water that doesn't exist in the open ocean. To measure rates of oxygen consumption and carbon dioxide production by microorganisms living in sediments on the continental shelf of New Jersey, chemical oceanographer Clare Reimers of Rutgers University used *in-situ* sensors deployed from a NURP remotely operated vehicle. "What we're finding to my surprise," said Reimers, "is these sands that have hardly any organic matter in them at all are still becoming anoxic usually within two to five milliliters below the interface." This implies that fresh reactive organic materials (remains of phytoplankton) are rapidly being degraded by microorganisms consuming all the oxygen.


ALEXANDER MALAHOFF

Ocean observatory at Pele's Vents.

With two years' worth of data, Reimers observed concentrations of carbon dioxide in the water at its highest (and oxygen at its lowest) in the summer and fall months when the ocean acts as a source of carbon dioxide to the atmosphere. In winter months, the opposite is true. Carbon dioxide levels are lower than the atmosphere and the coastal ocean acts as a sink. "Overall, it appears that the coastal ocean is not acting as a major source or sink for atmospheric carbon dioxide," Reimers said. "It's an important piece of information for global modelers, because it tells them that if all coastal systems acted like this one, they could ignore coastal regions in their global carbon dioxide balances."